



University of Pennsylvania Working Papers in Linguistics

Volume 25

Issue 1 *Proceedings of the 42nd Annual Penn
Linguistics Conference*

Article 22

2-27-2019

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Abstract

In a great number of languages, the presence or absence of word-medial vowels - especially schwa - is a type of variation that has drawn the interest of a number of scholars. By comparison, the variable production of schwa at the end of otherwise consonant-final words in French has gone relatively unexplored. The present study describes an analysis of word-final French schwa using Stochastic Optimality Theory to account for rates of word-final schwa in different contexts. The phenomenon is a striking example of the Richness of the Base in action in that, while schwa rates vary by context, there appears to be a potential for schwa production in all consonant-final words. This is true both for words that end in an orthographic 'e' (e.g. page 'page') and words that don't (e.g. lac 'lake'), although word-final schwa appears more than twice as frequently when there is such an orthographic 'e', suggesting that it reflects a non-ubiquitous underlying vowel. Ultimately the essential variable character of word-final schwa is explained by a tension between two competing pressures that are observed elsewhere in French phonology: to align stress with the rightmost syllable in any given word, and to repair word-final codas with an unstressable vowel. We supplement this basic locus of variation with other constraints to account for rates of schwa across orthographic and phonological environments. Additionally, we demonstrate that constraint values producing schwas with a similar distribution to that in the observed data are learnable with a scaled-up version of the observed data as input.

Variable Word-Final Schwa in French: An OT Analysis

Ruaridh Purse*

1 Introduction

A considerable amount of work in the areas of phonetics and phonology has been devoted to investigating the elision and epenthesis of unstressed vowels in various languages (e.g. Zwicky 1972, Hooper 1978, Tarone 1980, Broselow and Finer 1991, Glowacka 2001), and French is no exception (e.g. Anderson 1982, Fougeron and Steriade 1997, Bürki et al. 2010). However, the vast majority of this research focuses on the behaviour of word-internal vowels and their interaction with the consonants that flank it. In particular, there are questions regarding the propensity of said consonants to cluster or be separated according to the phonotactics of a given language. A much less extensively studied phenomenon is the variable production of schwa ([ə]) following consonants at the end of words in French.

Sites for a potential word-final schwa are extremely widespread in French. Any word that would otherwise end in a consonant is a candidate. This is not only true for words that end with an orthographic <e>, but also words with word-final consonants and no <e> in the orthography. For example, *page* ('page') is [paʒ] or [paʒə], and *lac* ('lake') is [lak] or [lakə]. Words ending in a obstruent-liquid sequence (e.g. *table* 'table' [tabl(ə)]) are also relevant since a word-final schwa is variable in those too, despite the infelicitous syllable structure – a sharp rise in sonority within the coda – without it. In the past, it has been proposed that variable word-final schwa in French is the result of a several variable processes. These include a Southern French 'feminine' schwa linked to orthographic <e>, Parisian French 'prepausal schwa-tagging', and a 'phonetic lubricant' schwa used to break up particularly phonotactically egregious consonant clusters at word boundaries (Hansen 1997, 2003). These processes reflect valuable insights into the nature of word-final schwa and the frequency of its implementation in different contexts. Nevertheless, they form a sort of conspiracy towards stable variation between just two alternants in a single environment: word-finally following a consonant. The present study comprises a unified Stochastic OT analysis for rates of word-final schwa as observed in corpus data of spoken Parisian French.

2 Background

2.1 Historical Word-Final Deletion

As previously alluded to, a word-final orthographic <e> in French has a special status. This is the fact that it marks the presence of a historical schwa¹ that was invariant – other than processes of phonetic reduction that can be presumed to have existed (Schane 1968, Dell 1970). This vowel plays an important role in some relevant phonological changes the history of French. Namely, the widespread deletion of word-final consonants. The transition from Late Old French to Middle French and then to Early Modern French saw the deletion of almost all word-final consonants except when followed by a vowel at the beginning of the subsequent word, where 'liaison' occurs (Morin 1986). This is exemplified in the difference between *nous voyons* ('we see' [nuvwaʒɔ̃]) and *nous avons* ('we have' [nuzavɔ̃]). Crucially, a large number of consonants were protected from this process by a historical word-final schwa that followed them. The subsequent deletion of the historical word-final schwa resulted in a large number of new consonant-final words that occur with a word-final orthographic <e>. Since the historical word-final schwa was deleted after the process of deleting word-final consonants, the new word-final consonants were not deleted too. In essence, the two processes share

*Thanks to Eugene Buckley, Rolf Noyer and the attendees of PLC42 for their thoughtful comments. All errors or omissions are my own.

¹The precise quality of the historical vowel is not clear. I refer to it as the 'historical' word-final schwa to differentiate from the contemporary variable schwa that is the subject of the present study.

grand	[grɑ̃]	‘big MASC’	grande	[grɑ̃d]	‘big FEM’
petit	[pəti]	‘small MASC’	petite	[pətit]	‘small FEM’
gras	[ɡras]	‘fat MASC’	grasse	[ɡras]	‘fat FEM’

Table 1: Word-final consonant retention in feminine forms.

a diachronic counterfeeding relationship. These changes are most clearly observed synchronically in adjective gender-agreement alternations, as demonstrated in Table 1, without the variable schwa that is the subject of the present study.

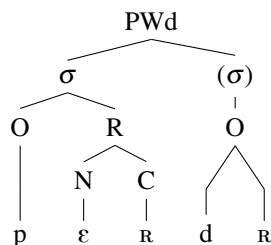
Classically, the synchronic derivation of the forms in Table 1 mirrors the diachronic facts. That is, there is an underlying schwa in words that end with an orthographic <e>. The underlying schwa shields a preceding consonant from a deletion process targeting word-final position, and is subsequently deleted itself. It is not sufficient to attribute variable word-final schwa to a residual manifestation of the historical word-final schwa, nor to an underlying schwa. This much is clear when you consider that variable word-final schwa is possible in French words that do not end in an orthographic <e> and have not historically had such a schwa. On the other hand, the notion that a word-final orthographic <e> reflects an underlying word-final schwa is crucial in accounting for the rates of variable surface schwa observed in different contexts.

2.2 Syllable Structure

The variable epenthesis or elision of schwa is a matter of syllable structure. An additional schwa is a nucleus to an extra syllable that takes an onset from existing preceding consonants according to the Maximal Onset Principle. A missing schwa means one fewer syllable and requires resulting consonant clusters to form phonotactically legal onsets and codas. Dell’s (1995) account of French rimes provides an attractive locus for the variation in word-final schwa based on syllable structure that must be addressed before proceeding with the analysis proposed in this paper.

Dell observes that sequences are licensed in word-final position that are not licit codas elsewhere. In fact, word-medial codas can consist of just one consonant at maximum, while a wide variety of clusters can appear word-finally, including obstruent-liquid sequences (e.g. *lettre* [lɛtr] ‘letter’). Addressing the asymmetry between word-medial and word-final positions, Dell proposes that French syllables must contain one of two types of rime, simple or compound. Simple rimes can contain one coda consonant at most, and occur everywhere but in a word-final syllable (e.g. [ap] in *abstrait* ‘abstract’). Compound rimes (e.g. [ɛrdʁ] in *perdre* ‘to lose’) in fact consist of a simple rime ([ɛr]) and an onset to a degenerate syllable ([dʁ]), and occur word-finally. The ‘compound rime’ is illustrated in (1) for *perdre*.

(1)



This analysis would be convenient for accounting for word-final schwa as a tension between prohibiting word-final schwa (either through faithfulness to a schwa-less form or against the markedness of a schwa-ful form) and repairing a syllable with no nucleus. Nevertheless, we must be cautious. An analysis that posits new rime types that are language-specific and position-sensitive is lacking in explanatory power. But this quibble aside, Dell’s account fails to capture the strong tendency for French vowels to respond to syllable structure. One such phenomenon is known as the *loi de position*, and it stipulates that mid vowels should be tense ([e], [ø], [o]) in open syllables, and

sot	[so]	‘silly MASC’	sotte	[sɔt]	‘silly FEM’
rigolo	[ʁigɔlo]	‘funny MASC’	rigolote	[ʁigɔlɔt]	‘funny FEM’
idiot	[idjo]	‘idiot MASC’	idiote	[idjɔt]	‘idiot FEM’

Table 2: [o] ~ [ɔ].

heureux	[øʁø]	‘happy MASC’	bonheur	[bɔnœʁ]	‘happiness’
veut	[vø]	‘want 3SG’	veulent	[vœl]	‘want 3PL’

Table 3: [ø] ~ [œ].

premier	[prəmje]	‘first MASC’	première	[prəmjeʁ]	‘first FEM’
dernier	[dɛʁnje]	‘last MASC’	dernière	[dɛʁnjeʁ]	‘last FEM’
charnier	[ʃaʁnje]	‘grave’	charnière	[ʃaʁnjeʁ]	‘hinge’

Table 4: [e] ~ [ɛ].

lax ([ɛ], [œ], [ɔ]) in closed syllables. As noted by Féry (2003), this directly conflicts with a large number of French words as parsed according to Dell’s (1995) account. That is, the compound rime as described is used in every word-final context, and always includes an onset to a d— syllable. As such, according to the Maximal Onset Principle, *règle* (‘rule’) must be parsed as an open syllable followed by an onset ([ʀɛ.ɡl]). This would have to constitute an exception to the *loi de position* as a lax vowel now occurs in an open syllable. Unfortunately, this is the case for a large number of French words, to the extent that the insight of the *loi de position* is all but lost. Some tense-lax alternations whose lax alternants are rendered part of open syllables by a compound rime analysis are shown in Tables 2–4.

It is clear that Dell’s analysis represents some key insight about word-final consonants in French. Indeed, the account in present study is also largely predicated on the notion that codas are largely dispreferred, and resyllabification into an onset is optimal (along with other crucial components to the analysis). However, the *loi de position* provides compelling evidence against onset-hood as a general structural property of French word-final consonants. At the very least, some stage of phonology must represent word-final consonants as codas, closing their syllable. As such, a new locus of schwa variation – or another way to induce this one – is required.

2.3 Schwa, Underlyingly

In terms of vowel quality, modern schwa is not distinct from the lax mid-front rounded vowel [œ] (Tranel 1981), which appears in words like *neuf* (‘nine’ [nœf]). However, the two vowels can be differentiated in terms of their phonological behaviour. Crucially, French schwa exhibits a degree of ‘instability’ – a propensity for insertion and deletion – that is not found in any other vowel, and it is the only vowel that cannot carry stress. This latter observation is easily demonstrated with the simple fact that French has consistent word-final stress; an ‘accent de mot intrinsèque’ (Rousselot 1908). This is true for all contexts except when the final syllable in a word contains a schwa. In those cases, stress is pushed to the penult. Accounting for the acoustic identity and phonological dissimilarity of schwa and [œ], Anderson (1982) proposes that the two vowels must not share an underlying representation. Specifically, the facts about the phonological behaviour of schwa can be captured if it is underlyingly represented as an empty (featureless) vowel slot. This assumption will also be crucial for the analysis put forward in the present study.

The proposal that schwa is underlyingly an empty vowel slot presupposes an underlying structure that is rich in syllabic structure. This approach follows from a tradition of Government Phonology (Kaye et al. 1985), in which the syllable is the surface realisation of necessary hierarchical structures that are shared between all languages. Such structured representations stand in opposition to classical models of phonology that only recognise the segment as the structural unit of representation. However, work in Autosegmental Phonology, as well as work on metrical structure

(e.g. Liberman and Prince 1977), have sufficiently established the importance of larger structures in deeper phonology. At the same time, this analysis of schwa as an empty slot underlyingly relies on the regularity of syllable structure such that the presence of a syllable necessitates the presence of a vowel slot that can be left empty. Interestingly, while Dell's (1995) account is in some sense the progeny of the same Government Phonology (GP) tradition, the original GP observations about unifying structures in phonology are somewhat incompatible with a compound rime account, in which it is claimed that French syllables should have different basic structures depending on word position.

2.4 Stochastic OT

Stochastic Optimality Theory (OT) is a phonological framework that allows us to analyse probabilistic outcomes as an integral part of the grammar. Given the systematic and highly variable nature of French word-final schwa, it is extremely well-suited. Variable configurations of OT are quite distinct from the classical formulation (Prince and Smolensky 1993), in which an obligatory ranking of violable constraints should always result in one 'optimal' candidate that is observed in the output. This reading of classical OT, however, is obviously ill-equipped to deal with the systematic phonological variation that is apparent in almost every instance of language use.

Some progress has been made in terms of addressing variable phonology with minimal changes to the classical OT architecture. In particular, some effort has been made to address how the partial ranking of constraints can be used to produce multiple possible outputs (e.g. Kiparsky 1993, Anttila 1997, Anttila and Cho 1998). In such analyses, certain constraints are crucially unranked with respect to one another, such that different relative rankings will produce different outputs. For certain phenomena, this approach can even approximate the quantitative reality of the rates at which certain variants are used. For example, given two crucially unranked constraints, a grammar like this should predict that a variable is realised in two ways and that these variants should each appear in approximately half of the relevant contexts. This is because there is no component of the grammar weighting one ranking of the constraints over the other, and so they should be held to be in flux with one constraint winning over the other in 50% of the instances that EVAL is run. Therefore, the partially ordered constraints framework is a useful tool for isolating the grammatical pressures that give rise to a particular variable phenomena. However, this is rarely sufficient for accounting for actual variant rates, which are rarely so neat as to be captured by the logically possible permutations of a handful of constraints.

Stochastic OT (Boersma 1997) is a framework that addresses exactly this problem. In this probabilistic progeny of the standard generative model, constraints are given numerical 'values' that correspond to ranking at EVAL. For any two constraints, the constraint with the higher value will be ranked above the constraint with the lower value. Before each EVAL, though, constraint values are perturbed on a normal distribution with a mean that corresponds to the starting place of a given value. This means that constraints whose values are sufficiently distant essentially have an obligatory relative ranking and will never be reranked with respect to one another. On the other hand, constraints whose values are close will exhibit reranking at a rate that matches the probability of instances of perturbation that will result in a reranking. Constraints can be assigned values to approximate the variation observed in real data.

A second important component of the Stochastic OT framework is the Gradual Learning Algorithm, through which the acquisition of constraint values can be modeled (Boersma 1997). The algorithm is given a set of constraints with starting values, and a body of input data that consists of UR-SR pairs. In each case where the input does not match the output of the current grammar, the values of constraints undergo adjustment according to a 'plasticity' parameter that corresponds to the numerical value by which a constraint can be altered. The adjustment procedure subtracts a number equal to the plasticity from the values of constraints that are violated by the candidate matching the one in the learning input. The fact that this candidate did not win is what triggered adjustment in the first place. Simultaneously, the same plasticity number is added to the values of constraints that are violated by the candidate that was the winner in the learner's own grammar. This way, constraint values are gradually altered to approximate the input.

3 Methodology

2,667 tokens from 8 native speakers of Parisian French were coded for speaker, word, and phonological environment of the potential schwa site. The data come from 2 corpora, ETAPE (Gravier et al. 2012) and BREF80 (Gauvain et al. 1990, Lamel et al. 1991). The data from the ETAPE corpus was taken from a debate about raising the retirement age in France, on the television show *Pile et Face*. BREF80, on the other hand, consists of recordings of speakers reading aloud from passages of the news publication *Le Monde*. Each token was a consonant-final word when it appears without schwa and was coded for speaker, word, and the phonetic environment of the potential schwa site. In total, 390 tokens (15%) had word-final schwas. All factors discussed in this study were found to significantly affect the rate of schwa presence in a mixed-effects logistic regression model with random intercepts for speaker and word variables. Speaker gender and corpus source had no effect on surface schwa rate and are not treated any further.

In terms of phonological analysis, the present study makes use of partially ordered constraints for identifying the locus of variation in word-final schwa. Subsequently, Stochastic OT is used to test whether a constraint set is learnable and sufficiently approximates distributions in real data. We follow Boersma and Hayes (2001) for appropriate settings of Gradual Learning Algorithm parameters. Initial constraint values are all set to 100 and plasticity is set to 0.1. Constraint sets are then trained on virtual corpus of 1 million tokens with the desired distribution of variants, and the learned constraint values are observed in an output of 100,000 tokens.

4 Analysis

4.1 Orthographic <e>

One key factor that seems to robustly condition the rate of word-final schwa is orthography. Specifically, while all consonant-final words seem eligible to surface with a word-final schwa, this occurs more than twice as often in those words ending in an <e> in their orthography. Words ending in <e> surface with a word-final schwa 18% of the time, compared to 7% of the time in words without an <e>. This suggests some fundamental difference between these classes of words. In order to shed more light upon it, we must identify the elements of the grammar that give rise to variation in the first place.

Word-final schwa appears to be an unusual manifestation of a classic dispreference for codas, often held to be a universal constraint on languages of the world. Only words that would otherwise be consonant-final are eligible sites for a word-final schwa. The schwa allows these consonants to be resyllabified as onsets. The simplicity of this approach is its virtue, and a constraint against codas (formalised NOCODA) will indeed play an important role in the analysis. However, some additional explanation is required as to why undesirable codas are repaired with a schwa. After all, a different word-final vowel could satisfy the pressure to put stress on the final syllable.

This pressure for lexical stress to fall on the final syllable of a given word (ALIGNSTRESSR) is another key component of the analysis. As previously mentioned, Anderson's (1982) insight that French schwa is underlyingly an empty vowel slot is meaningful in that it explains crucial phonological behaviours of the vowel. Namely, it cannot bear stress (*STRESS[ə]), and it lacks 'stability' in that it appears to undergo epenthesis and elision easily. This latter property is best characterised as a special response to faithfulness constraints. More specifically, we can propose the inviolable constraint DEPF, to prevent the insertion of featural content. On the other hand, the insertion of featureless structural content – schwa – is not a violation. Taken together, these observations betray a tension between structures that is a convenient locus for the variation we observe in the data.

This constraint set allows us to neatly model the variation observed in words without an orthographic <e>. This is demonstrated in a partially ordered constraints tableau, (2), for the word *lac* ('lake'). The shaded columns are those that are crucially unranked such that they can compete and affect the winning candidate.

(2) No orthographic <e>

/lak/	*STRESS(ə)	DEPF	MAXC	ALIGNSTRESSR	NoCODA
☞ a. 'lak					*
☞ b. 'la.kə				*	
c. la'kə	*!				
d. 'la			*!		
e. la'ki		*!			

For the purposes of the matter at hand, the keen observer will notice that we must also propose a faithfulness constraint along the lines of MAXC. This prevents an alternative repair of the word-final coda: deleting it altogether. This is applicable for the narrow scope of the current grammar, in which it can be interpreted as standing in the place of more complex and often opaque analyses that result in the retention of a word-final consonant. Namely, the counterfeeding relationship between the deletion of a consonant and the deletion of the abstract historical schwa, or the special status of word-final consonants for which the historical schwa analysis is inappropriate but that are nevertheless retained. However, the use of this constraint would need to be revised or augmented in broadening the analysis to the behaviour of French more generally, where consonant deletion (at least in most accounts) is not rare.

It remains, then, to differentiate cases like (2) from those where the word in question does have an orthographic <e>. The difference is most elegantly captured by stipulating that the presence of an orthographic <e> reflects the presence of an underlying vowel slot. Then we can propose one further constraint, MAXV, against the deletion of vowels. This means that there is an additional constraint that disfavors the schwaless variant of words with an orthographic <e>. As such, these words will surface with schwa significantly more frequently. This is shown in the tableau in (3) for the word *page* ('page').

(3) Orthographic <e> (underlying vowel)

/paʒə/	*STRESS(ə)	DEPF	MAXC	ALIGNSTRESSR	MAXV	NoCODA
☞ a. 'paʒ					*	*
☞ b. 'pa.ʒə				*		
c. pa'ʒə	*!					
d. 'pa			*!			
e. pa.ʒə'ta		*!				
f. pa'ʒi		*!				

This constraint set depicts a plausible locus of variation in word-final schwa, but it remains to be seen if it can sufficiently approximate the rates of schwa that are observed from real data. In order to test this, the constraint set was used as the starting point for a Stochastic OT grammar. After training on an input of 1 million tokens in words with and without orthographic <e>, with the observed distribution of schwa and schwa-less variants, the resulting constraint values were as shown in Table 5. These values were used to produce 100,000 tokens of each orthographic class. The distribution of these outputs that had a schwa closely approximated those observed in the corpus data, as demonstrated in Table 6.

Constraint	*STRESS[ə]	MAXC	DEPF	ALIGNSTRESSR	MAXV	NoCODA
Value	104.4	104.3	104.2	95.3	92.7	91.8

Table 5: Constraint values for rates of word-final schwa conditioned by orthography.

	Output	Observed
Orthographic <e>	19%	18%
No <e>	9%	7%

Table 6: Word-final schwa by presence of orthographic <e> in observed and artificial data.

Both types of word, those with and without an orthographic <e>, most frequently surface with no schwa. This is a striking example of a Richness of the Base phenomenon, whereby words that crucially differ in underlying representation can surface with the same structure because it will always occur in GEN as a possible output. The fact that weight is put towards a schwa-less form for both word types is also fairly elegantly captured in terms of the values of those constraints whose relative ranking is crucial for variation. That is, ALIGNSTRESSR is ranked most highly out of ALIGNSTRESSR, MAXV and NOCODA. As such, the pressure to put stress on the rightmost syllable of a given word often wins out against the pressure to resyllabify undesirable codas with the structure that least egregiously violates DEP: a featureless vowel slot that will surface as schwa.

4.2 Contextual Factors

While there is a robust basic pattern in the rate of French word-final schwa that depends on word class – the presence of orthographic <e> reflecting an underlying structural difference that manifests in an increased rate of word-final schwa –, there are several other factors that are relevant. In particular, the basic analysis must be augmented to capture the effects of phonological context. To address preceding contexts first, we must separate words ending in an obstruent-liquid sequence (e.g. *règle* ‘rule’) from other words ending in orthographic <e>. The infelicitous coda shape that is formed from the lack of a word-final schwa makes this class of words particularly likely to appear with a word-final schwa. Indeed, sometimes an alternative repair of this word class involves the deletion of the final liquid too. See Nagy and Reynolds (1997) for an Optimality Theoretic analysis of this type of deletion in Faetar, a Francoprovençal dialect where this repair is dominant.

In terms of following phonological environments, the main factor is whether a given word-final consonant can be resyllabified across a word boundary (*enchaînement*). When the following word begins with a vowel, resyllabification as an onset to this vowel is always possible. For following consonants, only those sequences which form licit onsets in native French words were categorised under the ‘possible onset’ heading. The following context effect becomes yet more complicated when you consider that the prepausal (phrase-final) context behaves differently still. For most words, the prepausal context is where word-final schwa appears most frequently. This makes sense when you consider that prepausally, you cannot even force a word-final consonant into an infelicitous onset; a consonant in this position must be a coda unless there is a schwa. However, for words ending in an obstruent-liquid sequence, it is in preconsonantal contexts where syllabification is impossible, and not prepausally, that word-final schwa is most frequently produced. Rates of schwa production in all consonant-final words is shown in Table 7 with token counts for three word categories in three following contexts.

	Possible Onset	Impossible Onset	Prepausal
Obstruent-liquid	21% (9)	70% (99)	36% (12)
Other <e>	6% (24)	12% (105)	23% (84)
No <e>	0% (0)	2% (12)	28% (45)

Table 7: Observed word-final schwa rate conditioned by contextual factors.

One striking thing about this data is that all three types of word-final schwa that have been recognised in past literature are evident (Hansen 1997, 2003). The orthographic effect that is associated with Southern French still remains, and the prepausal context shows a high rate of word-final schwa – a phenomenon associated with Parisian French. Even the ‘phonetic lubricant’ schwa at

word boundaries is clearly visible in the interaction between words ending in an obstruent-liquid sequence and a preconsonantal context where resyllabification as an onset is impossible. As such, these characterisations of word-final schwa types reflect insights about the nature of the phenomenon as a whole that are not restricted to the regions where they are stereotypical. With this in mind, we must revisit our constraint set and augment it for the purposes of dealing with contextual factors.

The basic constraint set is already equipped to deal with the difference in rates of schwa in words with and without an orthographic <e>. However, a constraint must be added to increase the overall frequency of schwa variants of words ending in obstruent-liquid sequences. We can formalise this as *SONSEQ*, a constraint enforcing a uniform decrease in sonority across a coda, such that an obstruent-liquid coda violates it. A second additional constraint should address the special status of prepausal condition in resisting consonants that must be codas, even with the most generous phonotactics. This constraint is **C]_{Phr}* and it is violated when a consonant appears immediately before a phrase boundary. Thirdly, the ‘phonetic lubricant’ property of word-final schwa must be implemented in a way that produces the rate of schwa we observe in obstruent-liquid-final words before consonants. This constraint can be formalised as something as simple as **CCC*, which constrains against a triple consonant cluster. Finally, since the matter at hand is contextual factors and we are dealing with phrase-level phonology, we must include one more constraint. *ANCHORL(PWd)* is an inviolable constraint that prevents coda repairs through word-initial vowel epenthesis of the type seen in Vimeu Picard (Auger 2001) from applying on the word following a relevant word-final consonant.

This set of constraints should be sufficient to capture the behaviour of the different word types in each different context. And after training on 1 million input tokens per cell in Table 7, each with a distribution matching that of the natural data, the constraint values were as shown in tables 8 and 9. And the 100,000 token output of these constraints was distributed as shown in Table 10, with observed values for comparison.

Constraint	MAXC	*STRESS[ə]	DEPF	ANCHORL(PWd)
Value	103	103	103	101

Table 8: Values for inviolable constraints.

Constraint	*CCC	ALIGNSTRESSR	SONSEQ	*C] _{Phr}	MAXV	NoCODA
Value	-20	-23	-26	-26	-28	-30

Table 9: Values for constraints that are crucially and variably reranked at EVAL.

	Possible Ons.	Impossible Ons.	Prepausal
Obstruent-liquid	6% (vs. 21%)	74% (vs. 70%)	37% (vs. 36%)
Other <e>	6% (vs. 6%)	7% (vs. 12%)	27% (vs. 23%)
No <e>	0% (vs. 0%)	0% (vs. 2%)	25% (vs. 28%)

Table 10: Word-final schwa presence in artificial vs. observed data.

Those constraints whose ranking is high enough that they are never violated are presented in (8). These constraints limit those possible outputs to those that occur and do not take part in producing the variant rates that we see in the output of the Stochastic OT grammar. The constraints whose perturbation results in crucial rerankings are listed with their values in (9). This is an example of the way in which Stochastic OT analyses often lead to the loci of variation as a TETU (‘The Emergence of the Unmarked’) phenomenon. That is, it is in the relative ranking of very low-value – primarily markedness – constraints that the target variants are produced at the desired rates.

The constraint set proposed approximates the observed rates of word-final schwa in natural data for almost every category. The distributions produced in the 100,000 token outputs of the Stochastic

OT grammar are within 5 percentage points of the observed distributions in all but one case. The only case in which the artificial output did not closely approximate the observed rate of word-final schwa is in obstruent-liquid-final words preceding a vowel. The observed rate of schwa was 21% of cases, while only 6% of output tokens from the Stochastic OT grammar had a schwa. There are a number of possible solutions to this problem. One might stipulate more criteria for resyllabification across a word boundary, and impose further constraints that are violated by an obstruent-liquid coda. Alternatively, one could imagine a stratified phonology wherein obstruent-liquid-final words receive some treatment at the word level, before the following context is even a factor. Such solutions are beyond the scope of this analysis, which has proven successful in every other domain.

5 Conclusion

Accounting for variable phenomena with formal phonological tools continues to be a relevant endeavour. Word-final schwa in French, the variants of which are acoustically clear, is an especially worthy candidate for such a treatment. The present study constitutes a unified Stochastic OT analysis of the phenomenon, accounting for conditioning by word type and phonological context. Furthermore, the viability of the analysis is reinforced by the fact that, for the set of constraints proposed, ranking values can be learned from a limited input to produce an output closely approximating the distribution of schwa observed in real data. Ultimately, I advocate for a new locus of word-final schwa variation, the tension between aligning stress with the right edge of the word and the desire to repair codas with an unstressable vowel, that is only made more compelling by facts about stress and the phonological character of schwa in French.

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